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SYSTEMS ENGINEERING OF FUTURE STRATEGIC SYSTEMS

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FOREWORD

The Naval Submarine League sponsors an annual *Submarine Technology Symposium* for the purpose of exchanging information and examining the technologies that may enhance the operational capabilities of the submarine force. This paper was prepared for and presented at the Strategic Deterrence Session of the 1994 symposium on 10 May 1994.

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ABSTRACT

Future strategic systems will be developed to meet new and different requirements. Among these are the changes imposed by the evolving world situation and by the realities of defense budgeting. Systems-engineering disciplines have been applied to the development of strategic weapon systems with the result that requirements have been identified and met. The capabilities of existing Navy strategic weapon systems and the fact that they were developed within both budget and schedule are proof of this. In the future, however, this will not be sufficient. The *entire* strategic system, of which the weapon system is only a part, must be subjected to the systems-engineering approach if both system effectiveness and cost effectiveness are to be ensured. Application of these disciplines will lead to identification of the proper distribution of functionality across the system and the areas of technology that must be addressed to have the greatest impact on total system effectiveness.

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BACKGROUND

For more than thirty years, the mission of the Submarine-Launched Ballistic Missile (SLBM) force has been strategic deterrence. The object of attention during this period was the Soviet Union—a nuclear superpower. The nature and magnitude of the threat was largely responsible for the emphasis given the development of U.S. nuclear forces and for many of the design decisions associated with both the SLBM and intercontinental ballistic missile (ICBM) strategic weapon systems. More specifically, it was considered a given that the Soviet Union had the capability to threaten the national survival of the United States, and no cost was too great to pay if this threat was successfully prevented. The emphasis, therefore, was on weapon-system performance and reliability, not cost. Subsequent weapon-system upgrades—from A-1 to D-5—were also largely motivated by changes to the threat. These changes led to requirements for more range (for targeting and Fleet Ballistic Missile Submarine (SSBN) security), better accuracy (for improved targeting effectiveness and applicability to a wider variety of target types), and multiple warheads (for penetration of defenses and increased targeting flexibility).

In the past few years, the political and economic situations have changed, and some attention has been given to the associated changes needed in the definition of the strategic mission. The *STRATPLAN 2010* and *Future Deterrence Study (FDS)*, performed by the Office of the Chief of Naval Operations, are two studies addressing these changes. The *STRATPLAN 2010* study proposes that the strategic mission includes, in addition to strategic deterrence, theater support (offense and defense) and space control (satellite constitution and reconstitution and antisatellite (ASAT)). The *FDS* suggests that deterrence should be extended to include all weapons of mass destruction (WMD)—nuclear, chemical, and biological—and must address all WMD powers, not just the superpowers.

At the same time, the breakup of the Soviet Union and diplomatic efforts, such as START I and II, are changing the nature of the traditional nuclear strategic-deterrence mission and related operational and technical requirements. Nevertheless, this mission will continue into the future, albeit with reduced force and readiness levels. Economic factors, coupled with the reduced threat, militate against the development of either significant weapon-system upgrades or a new weapon system dedicated exclusively to this mission. The other missions proposed by the studies cited above and, especially the theater-support roles with their connotation of projecting power from the sea to the littoral, present an unfilled need and, perhaps, greater promise for the development of a new strategic weapon system. These missions and the requirements of the associated systems are discussed in more detail in the following sections.

FEATURES OF NEW STRATEGIC MISSION

What are these new missions? What is required to support them? Both *STRATPLAN 2010* and the *FDS* consider strategic deterrence a key element of the *new* strategic mission. They also consider how strategic deterrence in the future will differ from that of the past. In short, the threat is becoming smaller but more diverse. The historic threat from the Soviet Union still exists, at a lower level, from the nuclear-capable republics. Diplomatic means to reduce the threat (the START treaties) are continuing, but the threat will exist well into the future. Hence, that component of strategic deterrence that has been provided by the nuclear triad will continue to be required. It may well be that the SSBN force will be the sole or major provider of such deterrence in the foreseeable future.

There are other elements of strategic deterrence that must also be addressed. The *FDS* study highlights two components of this new requirement for strategic deterrence—other WMD and nonsuperpower nations. The proliferation of nuclear and ballistic-missile technology, the availability of chemical (and, perhaps, to a lesser degree, biological) production facilities, and the exporting of missile and weapon systems is resulting in the development of a widespread threat, albeit with limited capability. It can be argued that this new threat is not (and cannot be) effectively deterred by the existing SLBM force.

Studies such as the *FDS* emphasize that the destructive capability provided by the SLBM force is incompatible with the size of the threat posed by the weapons available to these lesser powers and, even more importantly, Third-World WMD do not pose a direct threat to the continental U.S. and certainly do not put our national existence at risk. If the SLBM is not a credible deterrent, then what would be? Studies such as *STRATPLAN 2010* (and others) suggest that a suitable weapon for this mission might be a single warhead missile with a very low yield nuclear or conventional warhead or a modification to an existing multiple independently targeted reentry vehicle(d) (MIRV'ed) system (such as C4 or D5) so that it would carry nonnuclear warheads. Large missiles would certainly be submarine based. Smaller missiles could be carried (if so designed) on both surface ships and submarines.

STRATPLAN 2010 also proposed a strategic theater support mission. As defined, this consists of both offensive and defensive missiles deployed on either submarines or surface ships. The Navy Theater Air Defense Office (PEO TAD) is developing or considering missiles, such as a Standard Missile variant (SM2 Block IVA) and a possible Navy Upper Tier interceptor, which fill the defensive mission need. This aspect of the theater support mission will not be discussed any further. The offensive need, in general, is for a missile that can provide a strike capability in the theater. The study addressed both small missiles (e.g., those compatible with the Mark 41 Vertical Launcher System and, hence, deployable on either an attack submarine, a suitably modified SSBN, or a surface ship) and variants of existing SLBMs—deployed on SSBNs.

Some examples of SSBN uses (and outloads) for this mission are shown on Figure 1. This need ranges from fire support of forces ashore to deep strike against time-critical or hard targets. A variety of warhead options (all nonnuclear) would be candidates. Naval guns with guided projectiles may be the most cost-effective solution at the low end of this range of requirements. A missile with capability at the upper end of this range could also satisfy many of the requirements of strategic deterrence discussed previously. While it is certainly unlikely that any one theater-support missile can satisfy all of the possible strike requirements; there may, however, be some technology and testing concerns that span the entire range. That is, there might be areas of common technology or testing opportunities of mutual interest.

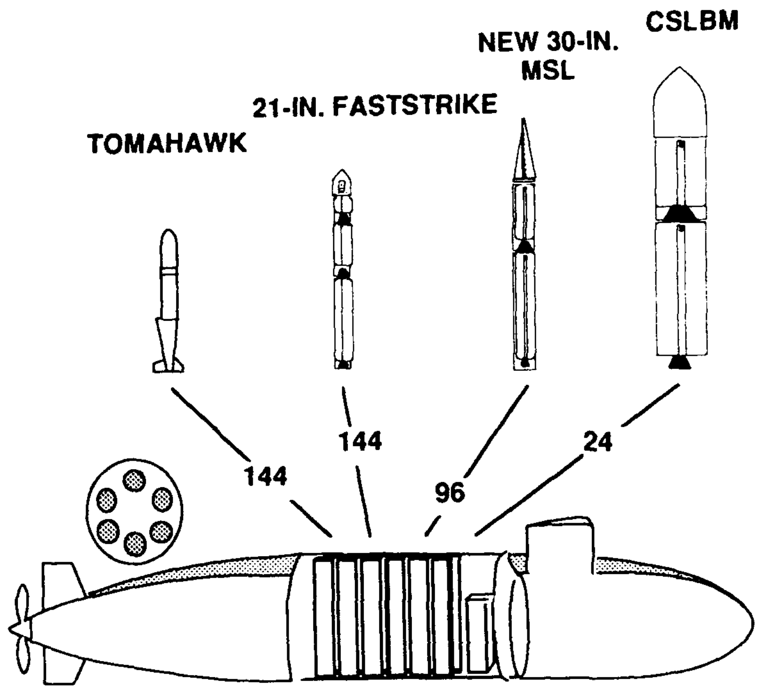

FIGURE 1. STRIKE MISSILE VARIANTS OF SSBN

APPLICATION OF SYSTEMS-ENGINEERING PRINCIPLES

Systems Engineering, in simple terms, is a structured process for identifying and controlling the components and relationships that make up a complex system. It involves the application of efforts necessary to transform an operational need into a usable system. This process is applied at all stages of the systems lifecycle—from the setting of requirements to decommissioning. One representation (adapted from Blanchard and Fabrycky) is given in Figure 2. Only a cursory examination of this figure is required to conclude that this is, in general terms, the process that was applied to the development of the SLBM systems. While this is certainly true of the weapon system itself and for each of its subsystems, it is also true in a larger sense. That is, the system did not end at the submarine hull. It included the shore facilities required for basing, logistics, and training; support to the strategic targeting community; and even extended to the development of external (but essential) systems such as the TRANSIT satellite. A key point is that in a given situation, it is important to define the system under consideration. In the case of the SLBM, the system was defined so that the elements required for success were included.

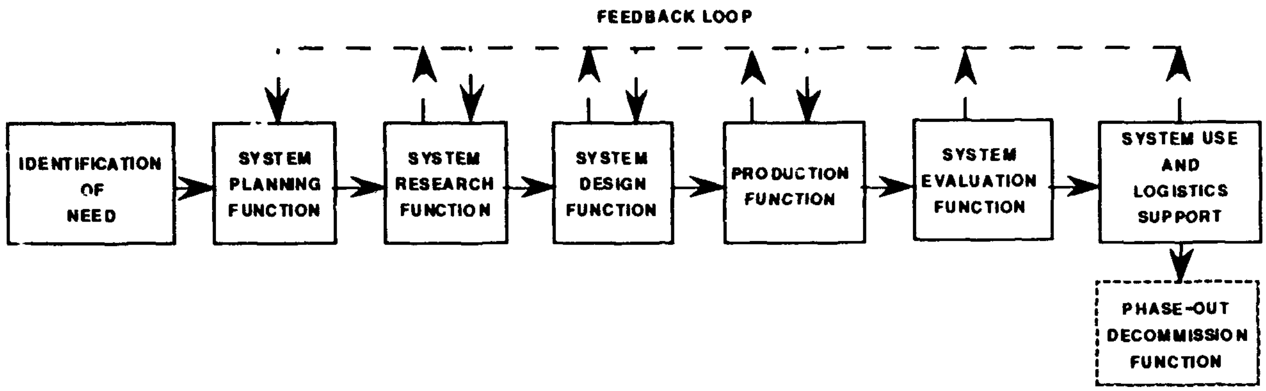

FIGURE 2. SYSTEM LIFECYCLE FUNCTIONS

It is not the purpose of this paper to address the systems engineering of a new strategic weapon system in detail. The structure of the process does, however, provide a framework for discussing the high-level requirements for such systems and for identifying the related technology issues (i.e., the first three functions of the process). It can also give some insight into the *proper* definition of the overall system. The first step in the process is the identification of need. At the weapon-system level, this drives us to a consideration of concept of operations, performance requirements, measures of effectiveness, and design requirements (such as environmental constraints and safety). The measures of effectiveness applied to the systems developed for the traditional strategic-deterrence mission have tended to emphasize system effectiveness and reliability. Thus, at the weapon-system level, this led to an emphasis on designing and developing a system that had the range, accuracy, warhead yield, and so forth, required to hold at risk the types and number of targets required by national strategic policy. Cost effectiveness was a consideration, but of lesser importance since no price was too high to pay to ensure national survival. There was also an implicit assumption that these systems were never going to be used except for flight tests. In other words, the system had failed to provide deterrence if it had to be used. This emphasis on performance led to a system definition that was inclusive. As noted above, the true system did not stop at the hull of the submarine.

What does this say about future strategic systems? A major difference is that cost effectiveness will be a high priority. This is a system (even if it is used to provide deterrence against Third-World WMD) that is designed to be used. Thus, it must be affordable and effective in its assigned mission. Cost effectiveness can be achieved in two basic ways—by building a sufficiently large number of systems so that the unit cost is reduced or by using the simplest solution (and lowest technology, including existing components) that meets system requirements. A critical issue in this latter case is to place reasonable but not excessive requirements on the system. An underlying assumption in either case is that unique interfaces will be avoided so that the system can make the widest possible use of existing infrastructure (e.g., launchers; weapons control; and battle management and command, control, and communications (BMC^3)). It will also be necessary to differentiate this system from others that can do essentially the same thing. For example, this system must be at least as cost effective as a competitor (such as a cruise missile for deep strike or naval guns for fire support) and must have an important capability not provided by the competitor. This factors into establishing requirements and may run counter to the desire to bound the requirements to enhance cost effectiveness.

The broad range of the missions discussed above highlights the first issue—what missions are to be addressed. Too narrow a focus may result in an optimized solution with limited applicability to other missions and, potentially, a high unit cost. Too broad a focus may yield a virtually unsolvable problem. In either case, the result is *not* likely to be a cost-effective system and, in the latter case, the system may not exhibit effective performance in some other important respects (e.g., sufficiently high probability of kill against required types of targets, range, etc.).

Consider a ballistic missile with theater or regional range (say 600 km, so that it is START compliant and does not count against nuclear warhead limits) that can hold time-urgent or hard targets at risk. A missile designed specifically for this mission might have multiple stages, a guidance system capable of providing precise impact accuracy, and a separating reentry body with several warhead options. It would be suitable for deep strike and would undoubtedly have a deterrent effect. It might not be suitable for fire support of forces ashore for any of a number of operational or technical reasons, such as limitations on minimum range, an unsuitable warhead type, or the inability to control the impact points of the spent stages. If this missile has such limits on its utility, then it is not likely that cost effectiveness will be achieved solely through the number of missiles built. It will be important to address cost in the design of the system.

But is it necessarily the case that a system designed for the deep-strike mission cannot be used for other missions, maybe even for fire support? It is certainly possible to design a missile that is *suboptimal* for either the deep-strike or fire-support mission, but which has some capability in both areas. The system-planning function must establish whether the available capability is useful, especially in comparison to other alternatives, and whether it is cost effective. Note also that missiles are unlikely to ever be a cost-effective solution to a requirement that can be met using naval guns. Missiles would only be preferred where greater lethality or longer range is required. This probably tends to shrink the gap between missiles that would be used for both deep strike and fire support and, thus, increases the probability that a *suboptimal* solution will prove useful. Another approach to cost effectiveness, in this situation, is commonality at the subsystem or component level. Warheads or guidance packages, maybe even a missile stage, may have multiple uses. A missile which is usable in different configurations—with either one or two stages, for example—or for different missions (such as Theater Missile Defense) may also be an acceptable solution.

The previous discussion has implicitly assumed that the *system* that should be considered is the missile itself. This is almost certainly not sufficient to ensure that the total system (or, perhaps, even the missile) is a cost-effective solution to the problem at hand. A cheap missile, for example, is not a bargain if a new platform must be developed to carry it. A more inclusive definition of the *system* will be appropriate. The unit cost of any subsystem (the missile itself, for example, in this larger context) may be reduced if functionality is properly distributed across this larger system and if existing technology and components can be utilized. This approach will be explored further after some more specific requirements and technology issues are detailed.

TECHNOLOGY ISSUES FOR FUTURE STRATEGIC SYSTEMS

The research and system-design processes follow the requirements-setting and system-planning functions. The fundamental requirement for any weapon system is that it deliver a sufficient energy density to the right place at the right time. In addition, a new system (such as a ballistic missile) must also fill a need that is not met by existing systems. Examples of such needs are strikes against time-urgent targets (it can get to the right place at the right time) or against hard targets where the lethality of a hypersonic missile is much greater than that of any available alternatives (it provides a greater energy density than is available from other systems). An additional advantage accrues from the ability of ballistic missiles to put ordnance on a target in a timely manner at a variety of ranges. Finally, cost effectiveness is a requirement and may also motivate some technology concerns. If these are accepted as the top-level needs, what are the associated requirements and technology issues?

Range is not as much a technology issue as it is a matter of system design. If a small missile is under consideration, then its maximum range will almost certainly be restricted so that it is START-treaty compliant. A need for strikes at very long ranges may be more easily met by adapting an existing SLBM system—by augmenting the guidance system with a global positioning system (GPS) for accuracy and adding conventional warheads in place of the nuclear armed reentry bodies, for example. Thus, the technology issues, if any, for a new small strike missile are more likely to derive from the requirements for a minimum range capability for the smaller missiles. It is reasonable to expect that most concerns will be addressed by missile design (e.g., number of stages, selection of appropriate materials, etc.). However, existing technology could be applied.

Lethality and, in particular, the energy density supplied by the weapon, is a prime area for the application of technology. The specific requirements are driven by the types and characteristics of the targets to be held at risk and by the desire, stated earlier, to use nonnuclear warheads. If kinetic energy is the lethal mechanism, then the basic determinants of lethality are impact velocity and warhead mass. For example, attacking soft, time-critical targets (such as mobile missile launchers) requires the application of relatively low energy at any one point, but may require that it be distributed over an extended area (e.g., a large number of small submunitions). Killing hard targets, on the other hand, requires the application of greater energy that must be focused on specific locations. Very hard or buried targets may require a level of energy that can only be provided by missiles in the SLBM class (from either the much greater impact velocity or larger payloads).

The key technology issues revolve around understanding the physics of kinetic-energy transfer to target structures in a variety of velocity regimes (from the Mach 6 impact velocities typical of small missiles through those required for hydrodynamic penetration). There are many computer simulations, but relatively little data (especially at velocities greater than Mach 3 or 4) are available for validation. This understanding is required to design the appropriate warhead for a given mission and target—small submunitions, large mass penetrators, penetrating rods, etc.

Another requirement, which is a major contributor to lethality, is to get the weapon to the right place. This has two aspects—identifying and precisely locating the target and accurately delivering the warhead to this target. Both aspects affect the design of the weapon and provide an example of the larger system that has been referred to above. Notionally, the target-location error and the weapon-delivery error combine to give the weapon-system accuracy that drives lethality. Figure 3 gives an indication of the *delivery accuracy* achievable with various implementations of existing technology (namely, using a GPS-aided inertial guidance system). These results are specifically for a short-range ballistic missile; but, since the use of GPS for postapogee guidance reduces the sensitivity of impact accuracy to missile range, these delivery accuracies should be generally representative. Significantly different delivery accuracy is achieved by the various implementations and, thus, in the engineering of the larger system, it is possible to trade off target location, delivery accuracy, and warhead design.

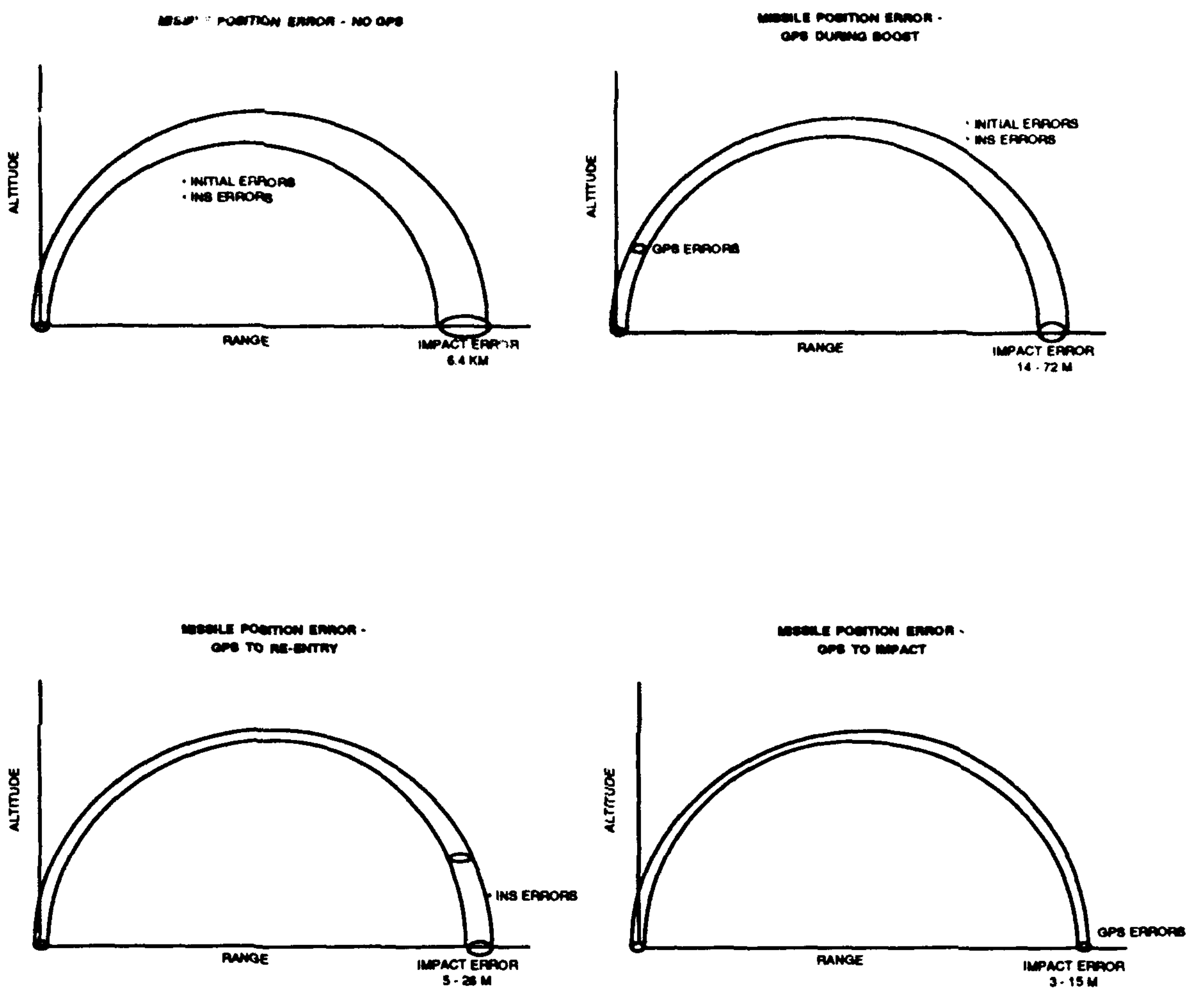

FIGURE 3. EFFECT OF GPS TRAJECTORY ON IMPACT MISS (1000-KM TRAJECTORY)

A specific example is given by consideration of mobile missile launchers. It may be a significant (and costly) technical problem to provide sensors capable of precisely identifying and locating such targets and providing targeting data in real time. Fortunately, the relative softness of the target allows the weapon designer to trade warhead design (namely, effectiveness area) for accuracy. That is, a suitable warhead design will provide some relief in the target location accuracy requirement. This requirement can be relaxed even more if the missile is capable of automatic target recognition and homing. The engineering of the large system must address all of these possibilities in the presence of other considerations, including cost.

Target location may be provided by assets beyond the control of the weapon designer; indeed, they may already be in place and capable of a known level of accuracy. In this case, the burden will be on the missile to provide whatever delivery accuracy is required (consistent with the warhead type) to give the overall system accuracy necessary for lethality. In an extreme case, this may lead to a requirement for which there is no cost-effective missile solution. A simple example is a hard-target killer requiring a system accuracy better than the available target location accuracy. The tradeoff may be between a seeker on the missile (assuming that the target has a detectable signature) and a new target-location system (or intelligence system, in the case of fixed targets). At a total system level, the cost-effective solution may be a new targeting system rather than an investment in a highly sophisticated (and costly) warhead.

The last requirement is to get the weapon to the target at the right time. For many types of targets (such as buried or hard targets), striking at the *right* time means arriving at the target at the time specified by advance planning. In these cases, there are no technology issues to be addressed. Striking time-critical targets is another matter. Mobile missile launchers, for example, might be located only after they launch a missile. They will only stay at that location for the length of time required for them to strike their equipment and leave. Thus, identifying and locating the target with sufficient accuracy, and then passing the targeting data to an available missile platform within these very stringent time constraints is a serious problem. In some ways, however, the solution to this problem exists (for example, the Joint Tactical Information Distribution System (JTIDS) may provide the required communication capability) or are operational issues (such as determination of suitable Rules of Engagement). The dominant technology issue, as in the previous section, is the sensor—how to identify and locate the target in a timely manner. The increased time criticality of the targeting and the potentially less demanding accuracy requirements differentiate this from that required for the location of fixed, non-time-critical targets.

Cost effectiveness is of the highest priority. This carries some implications relative to both technology and systems engineering. Ballistic missiles carry the stigma of being expensive compared to other weapons systems. This feeling derives mostly from experience with long-range, nuclear-armed ICBM or SLBM systems. Historical (and some current) data indicate that it is reasonable to build a small missile suitable for deep strike that has a per unit cost similar to that of a cruise missile. A prime application of technology, therefore, is to the production of a cost-effective ballistic missile. A reasonable goal for such a technology effort would be to achieve a per unit cost of approximately $500,000 for a small deep-strike ballistic missile.

Achieving this goal will also require careful systems engineering in addition to advances in missile production technology. Further, this effort can only be successful if this discipline is applied to the larger system. That is, the weapon is a subsystem that must be designed to fit into the larger system efficiently. Some of these steps are straightforward. The weapon system must integrate into existing systems with minimum impact. For example, the missile must meet Mark 41 Vertical Launching System (VLS) constraints if it is to be deployed on surface ships or attack submarines, and it must also accept existing ship's power and weapons-control system interfaces. To the extent that they satisfy operational requirements, existing BMC^3 assets (such as JTIDS) and architectures should be adopted.

As indicated previously, missile requirements should be traded off with other elements of the larger system to ensure that the missile is as simple and cost effective as possible. An example was discussed above—impact accuracy to ensure lethality. In theory, sufficient weapons-system accuracy can be achieved in a variety of ways—by trading target-location accuracy and delivery-system accuracy. Relatively imprecise target-location accuracy can be overcome by adding an automatic target-recognition and terminal-maneuvering capability to t .e weapon. Obviously, this has the potential to significantly increase both the development and per unit cost of the missile, and, depending on the complexity of the system and the number of missiles required, the lifecycle cost of the system. Is this the right solution? It is impossible to say without detailed consideration of the problem, but, intuitively, it seems that an alternative solution—improving the target-location accuracy of available sensors or affecting the requirements for proposed systems (unmanned aerial vehicles, satellites, etc.)—may be more cost effective. In simple terms, it puts the complexity in an asset that can be reused for this mission and to support others (such as Theater Missile Defense) instead of in the expendable part of the system (i.e., the missile). The requirements for target-location accuracy can be offset by inclusion of relatively simple systems (such as GPS-aided inertial guidance) that can yield very good (but not perfect) delivery accuracy.

A related issue, especially from a cost-effectiveness point of view, is to develop a missile that is appropriate for the mission. If, for example, the intended targets are very hard or deeply buried targets or if a range of several thousand kilometers is required, then a small missile is almost certainly the wrong choice. It may well be that the impact velocity and payload weight delivered by a modified SLBM are required for lethality. This is clearly a submarine mission since SSBNs provide the only suitable launch platform. If the targets are less hard or if this long range is not required, then other choices, including small missiles, become viable options. In this case, it would be desirable to take advantage of the large number of VLS-equipped platforms and deploy these missiles on either attack submarines or surface ships. As noted earlier (see Figure 1), select SSBNs could also be modified for this role and could carry a large number of small missiles. Finally, if the desired targets are extremely time critical (e.g., mobile launchers), then rapid and reliable communication to the launch platform is essential. Thus, even though the missile could be launched from either suitable submarines or surface ships, the appropriate launch platform is likely a surface ship.

Finally, there appears to be another area of systems engineering that holds promise for cost effectiveness—systems research. As noted throughout, systems that contribute to the performance of the new strategic mission range from those capable of fire support of forces ashore to those capable of long-range strike with conventional warheads. A determination of the optimal weapon for each aspect of this mission highlights the differences. Naval guns, for example, may be the most cost-effective weapon at one end of the spectrum, while modifications to existing SLBMs may best satisfy the needs at the other. In between, there may be a variety of small missiles tailored to the specific job at hand.

The similarity in all of these is that they share the technology required to accomplish their mission. The general areas—lethality, accuracy, and timely targeting—are the same and, to a degree, so are the solutions. GPS guidance, for example, is likely to be common to all of these systems and many of the missile systems, regardless of size and range, will be designed to use kinetic energy warheads. Thus, components developed for any of these systems should be considered for use in developing one of the others. Another requirement of systems research is to gather test data to evaluate these concepts. Some systems, such as SLBM, have an ongoing test programs. Their ability to carry test items (such as GPS receivers or warheads) to conditions (e.g., velocity) not easily attained in full-scale ground tests should be used to gather empirical data and to test system components applicable to any of a number of systems.

SUMMARY

This report has described some possible new strategic missions and the systems that might be developed to fulfill them. It also touched on the systems-engineering of these systems and the related technology issues. At a high level, the system requirements are to put sufficient energy density at the right place and at the right time. This leads to the identification of the following technology issues: (1) the design of nonnuclear warheads required for lethality against a variety of targets (and, especially, the physics relating the transfer of kinetic energy to a target structure at various velocities); (2) the development of a guidance system that delivers missile/warhead impact errors of a very few meters; (3) a system for providing accurate and timely target identification and location; and (4) cost-effective missile production. In addition, it has been suggested that technology applicable across a wide range of systems applicable to this mission can be tested, in a cost-effective way, by using the opportunities afforded by ongoing test programs.

As has been mentioned a number of times, cost effectiveness may be the most important consideration of all. A new system must perform a mission that an existing system cannot, and it must be at least as cost effective as the system it will supplant. It has been proposed that this can best be accomplished by applying the discipline of systems engineering to a system that encompasses all of the components required to successfully complete the mission.

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